Stellar Photometry: Basic Information

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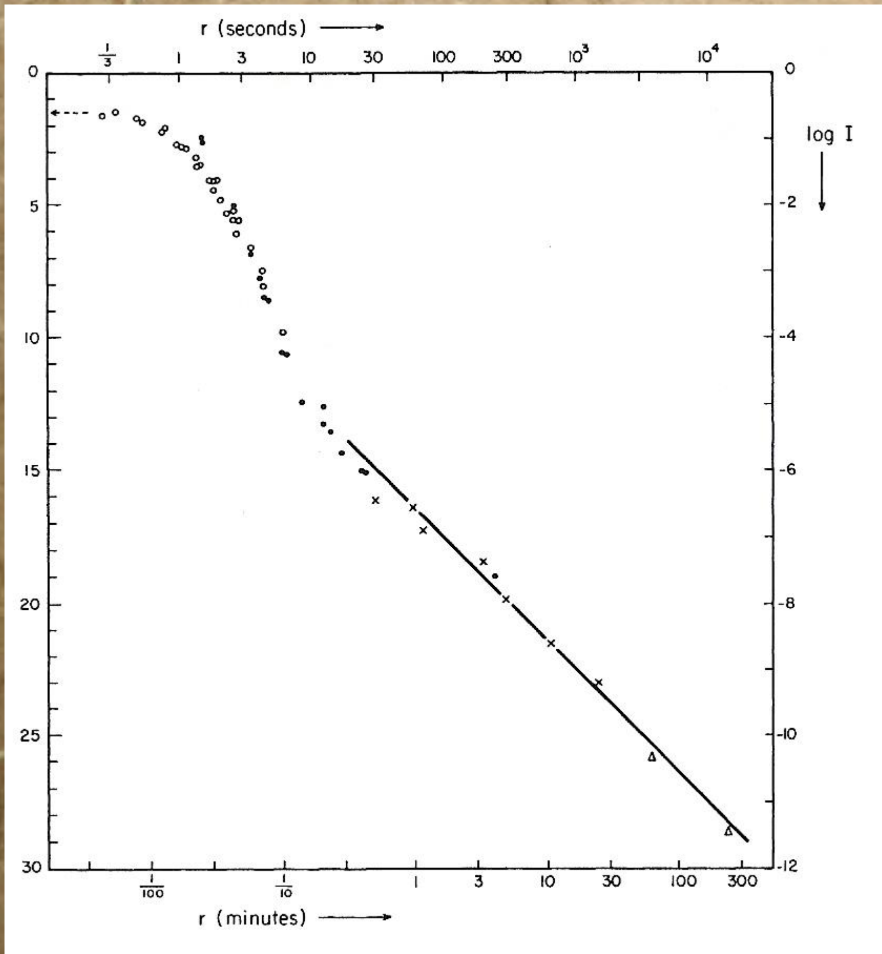
Point Spread Function

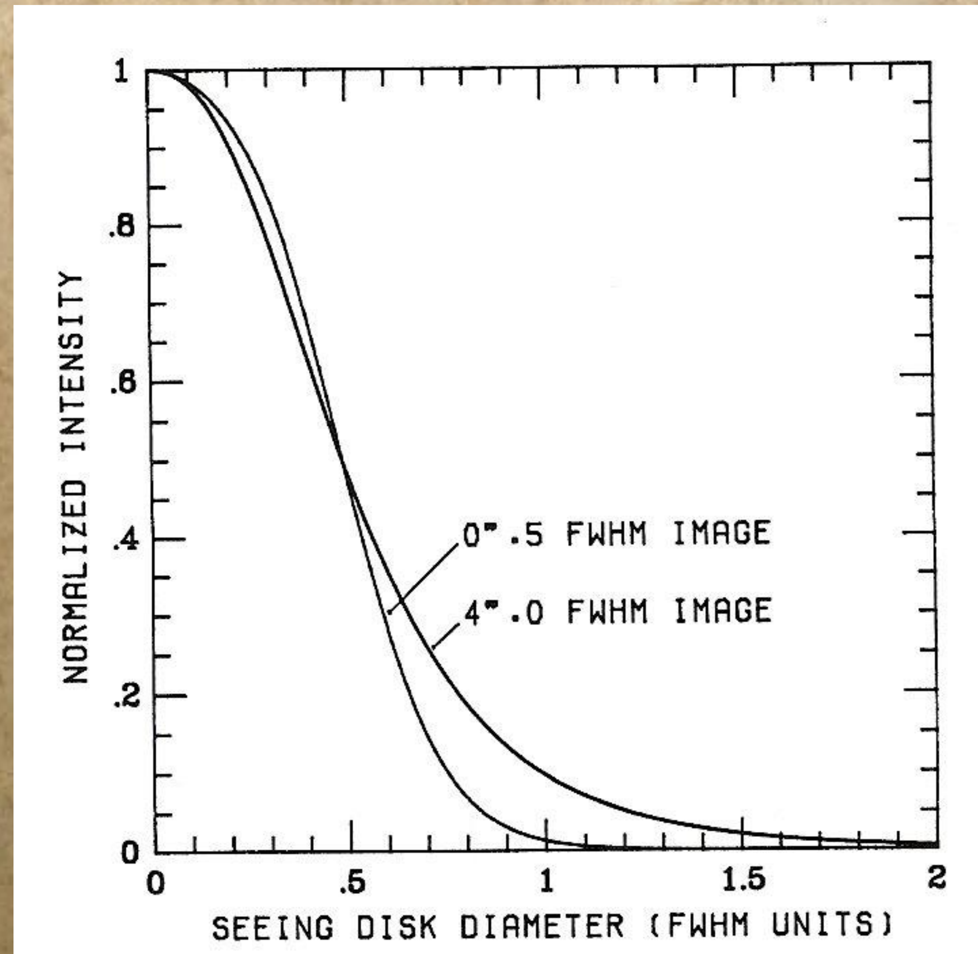
- Point source PSFs are most often modeled as Gaussian functions
- They are generally characterized by a single parameter - the FWHM
- Seeing and Encircled energy are useful as well

PSF II

- PSFs are only approximately Gaussian.
- They are Lorentzian in their core and Gaussian in their wings.
- shape changes with seeing.
- See King (1971), Diego (1985), Stetson (1987).

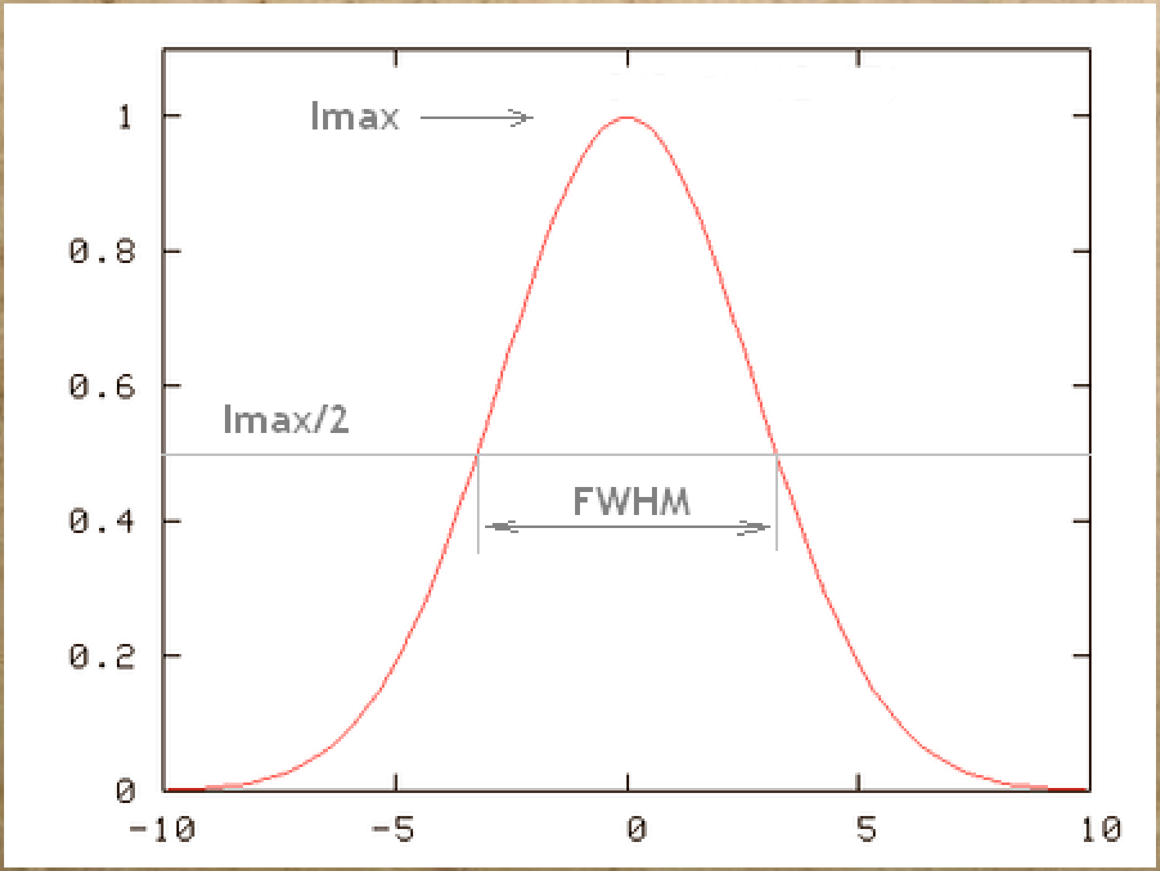
PSF III





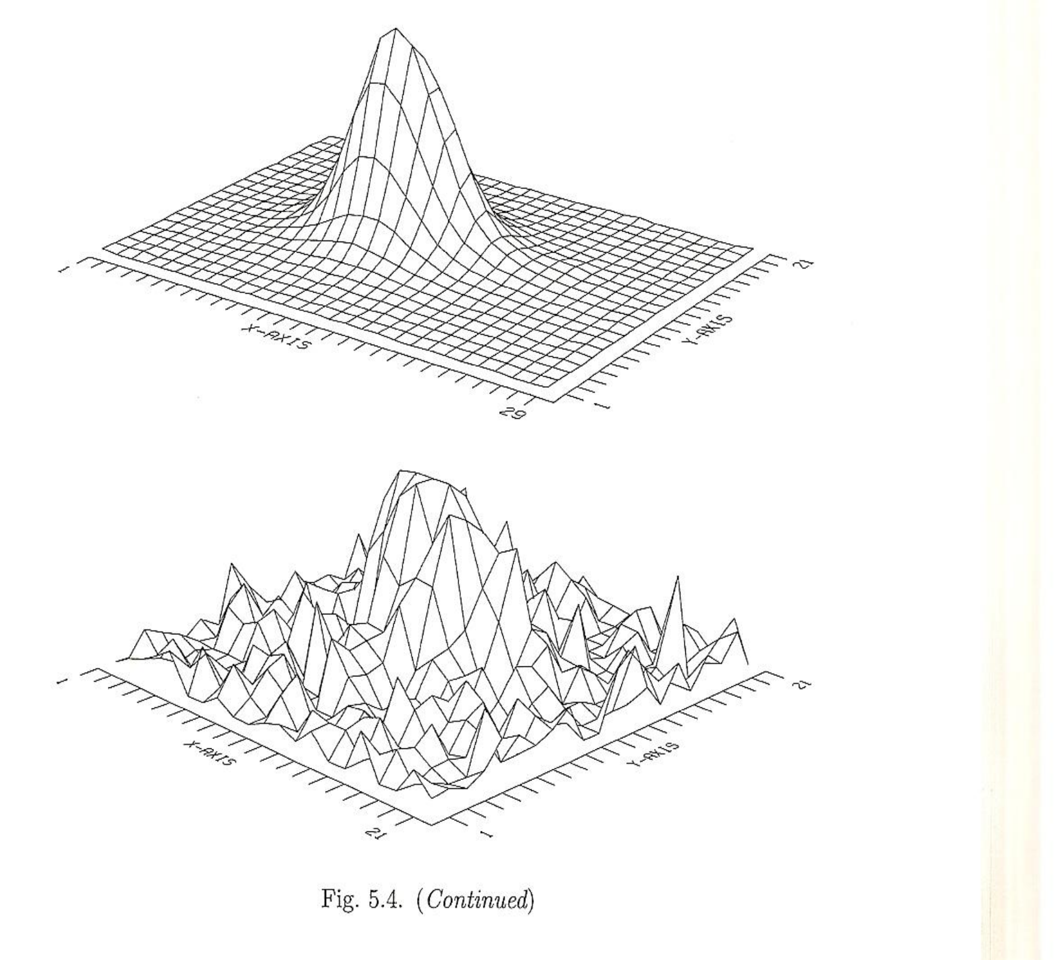
Left: “King” Profile showing large PSF extent and shape (King 1971).
Right: PSFs from the same camera, different seeing (Diego 1985).

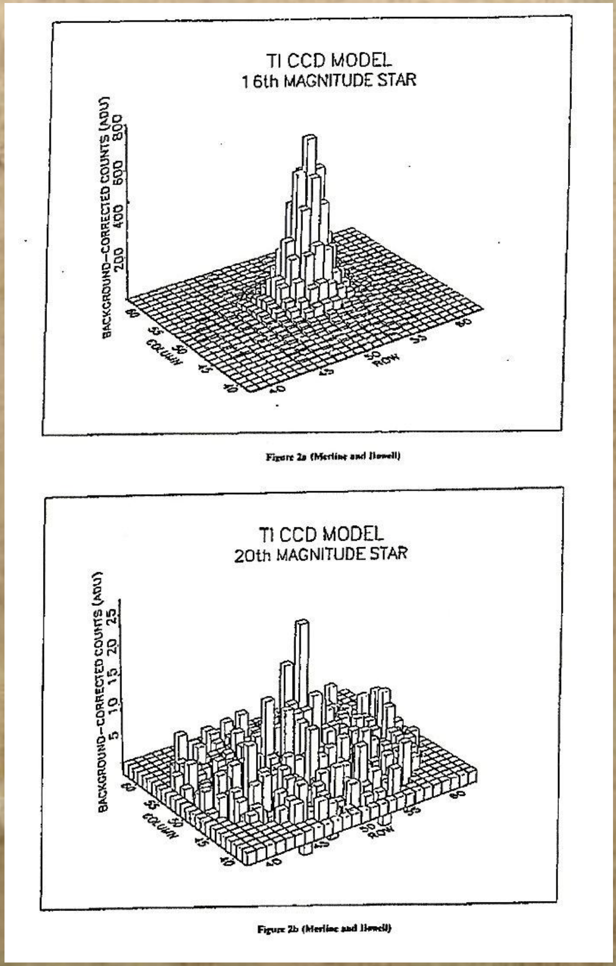
Idealized PSF



FWHM = Seeing value, typically ~1" from the ground

PSF appearance





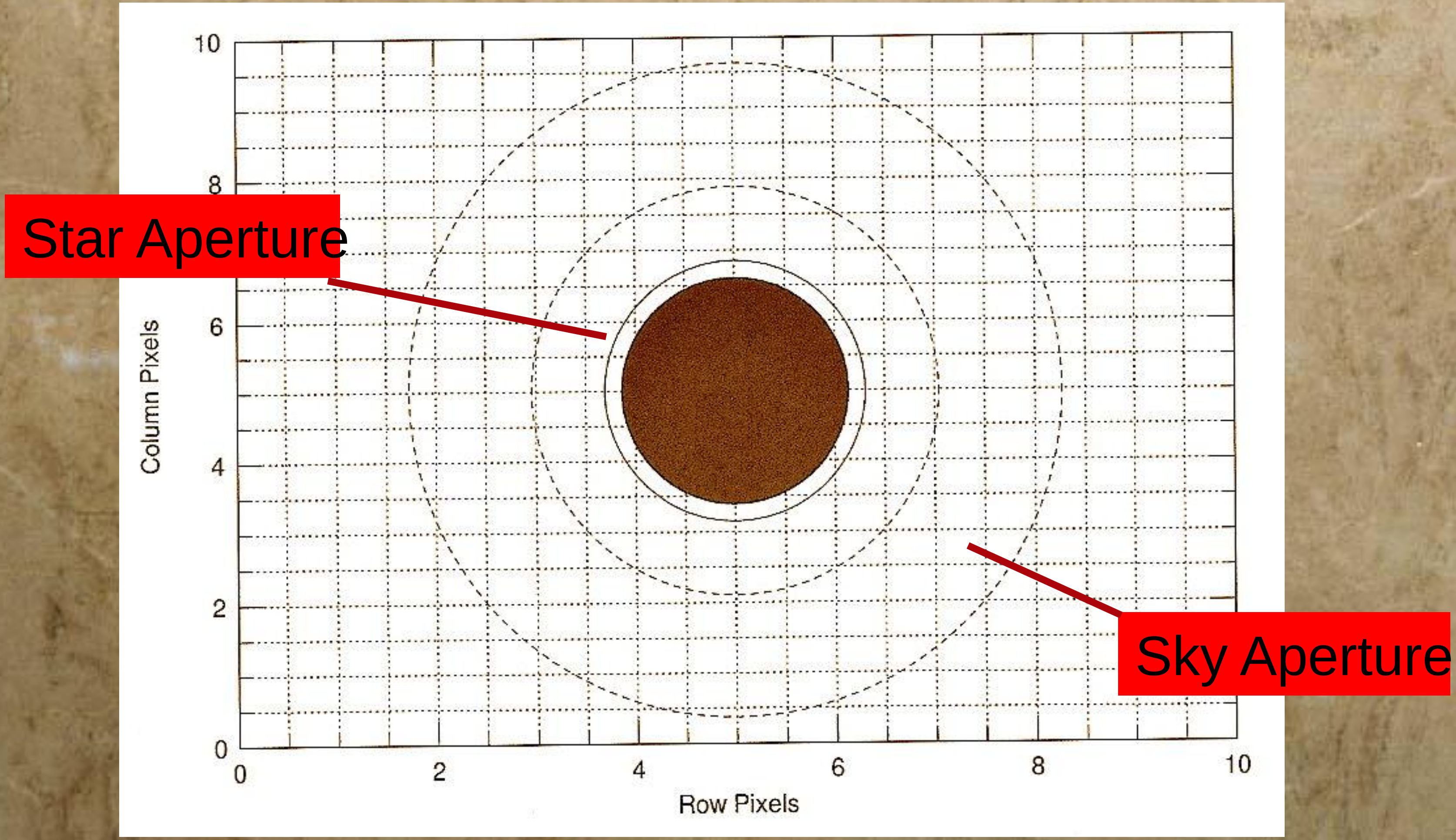
Spline fits (e.g. IRAF)

Pixel values

Estimation of Stellar Flux

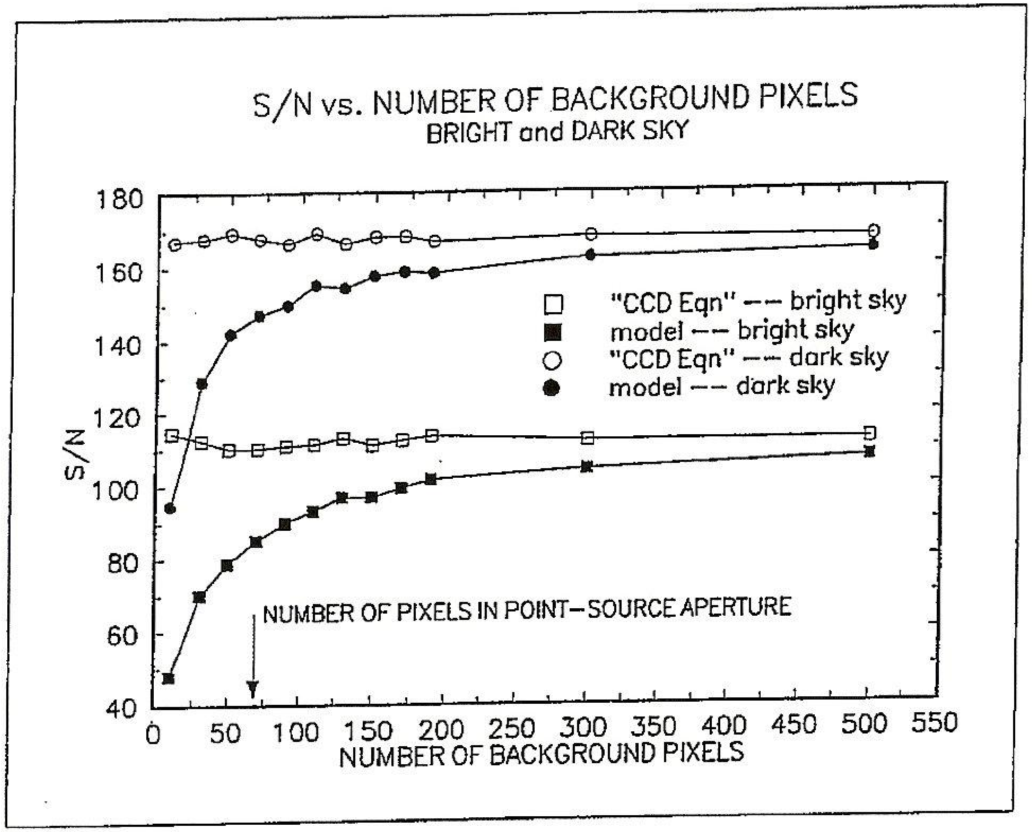
- A Simple source flux determination
- Mean bg (sky) level(B) = sum in bg annulus / number of pixels in bg annulus
- Source flux (N) = Sum in star aperture - (n(pix) * B)
- No consideration here of partial pixels, bg contamination, cosmic rays, etc. (see Merline and Howell 1995)

Est. of Stellar Flux: Aperture Photometry



Background Area

Background pixels vs. S/N



Signal-to-Noise

- How do we determine the S/N for a point source?
- What is the signal?
- What is the Noise?
- Once readout, the origin of each photoelectron is unknown; star, sky, dark current, cosmic ray, etc.

Signal

- If the “signal” equals the flux collected from a star = N*
- And If no other noise present, Poisson statistics prevail,

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_*}} = \sqrt{N_*}$$

- Above is ~true for bright sources (bright is defined as sqrt(N*) >> other noise contributions)

Encircled Energy vs. Aperture radius

Ideal, bright star PSF

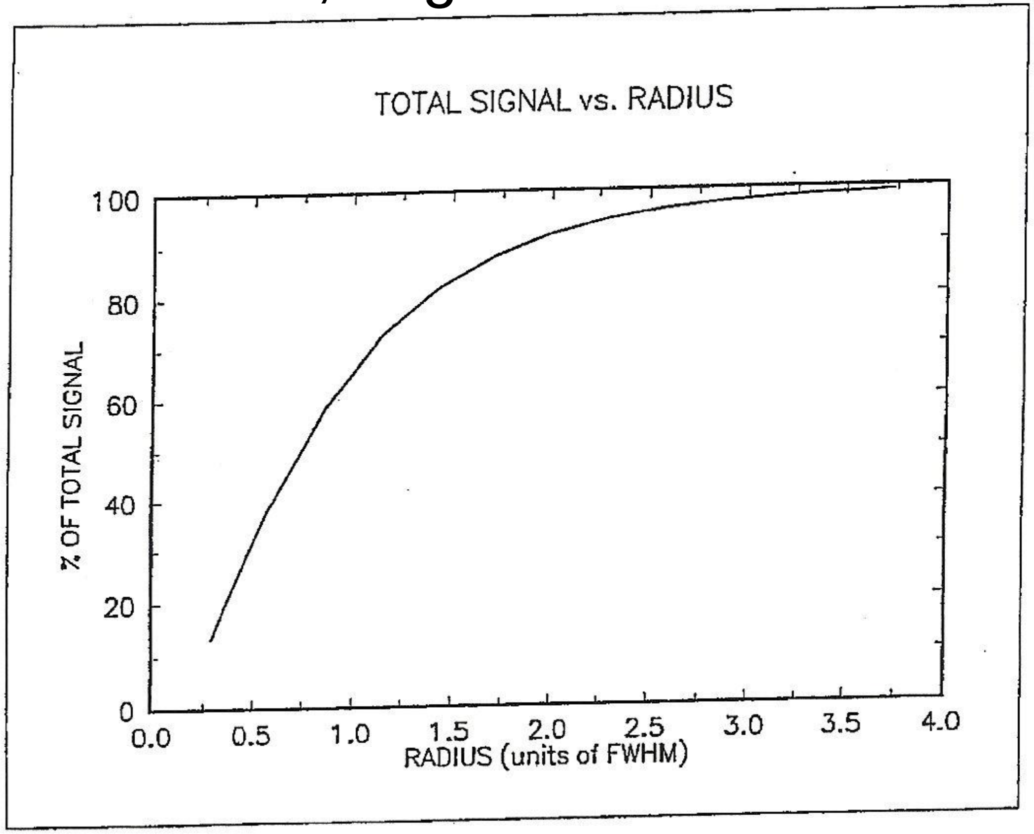


Figure 5 (Merline and Howell)

Major Noise Sources

- Photon noise form the source
  - SQRT (N)
- Photon noise from the sky
  - SQRT(mean sky) / pixel
- Thermal noise from dark current
  - SQRT(D) / pixel (exp. Increase w/ Temp, of concern for TE cooled CCDS)
- Read noise (generally low today)
  - Read noise / pixel
- Digitization noise - generally negligible

Other Noise Sources

- Fixed pattern noise or scene noise from flat fields
- Deferred Charge
- Gain variations
- Noise introduced during data processing/reduction
- Etc.
- See T. Brown's talk

(Complete) S/N Equation

$$\frac{S}{N} \simeq \frac{N_*}{\sqrt{N_* + n_{pix}\left(1 + \frac{n_{pix}}{n_B}\right)\left(N_S + N_D + N_R^2 + G^2\sigma_f^2\right)}} .$$

Expected Error in magnitude

Sigma(mags) = 1.0857 * (1/(S/N))

Differential Photometry

- If light curves with high photometric precision is your goal, differential techniques are for you
- The simple version:
  - Three stars V,C,K
- The better version:
  - Local ensemble differential photometry

Differential Photometry

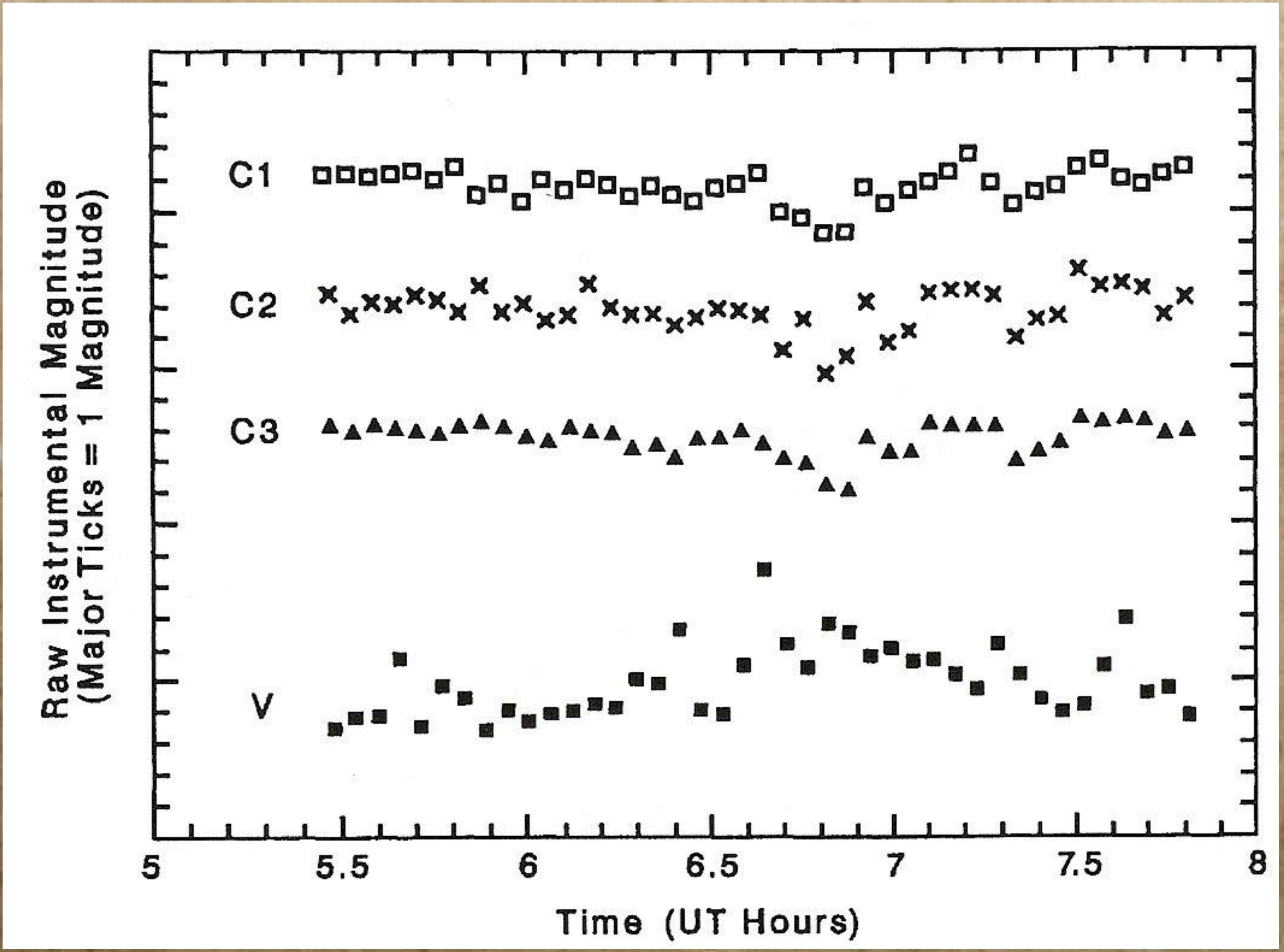
- V = suspected variable (or star of interest) and (assumed) constant stars = C,K
- Form magnitude differences V-C, and C-K, and assume...

$$\sigma^2_{V-C} = \sigma^2_{V-C}(VAR) + \sigma^2_{V-C}(INST)$$

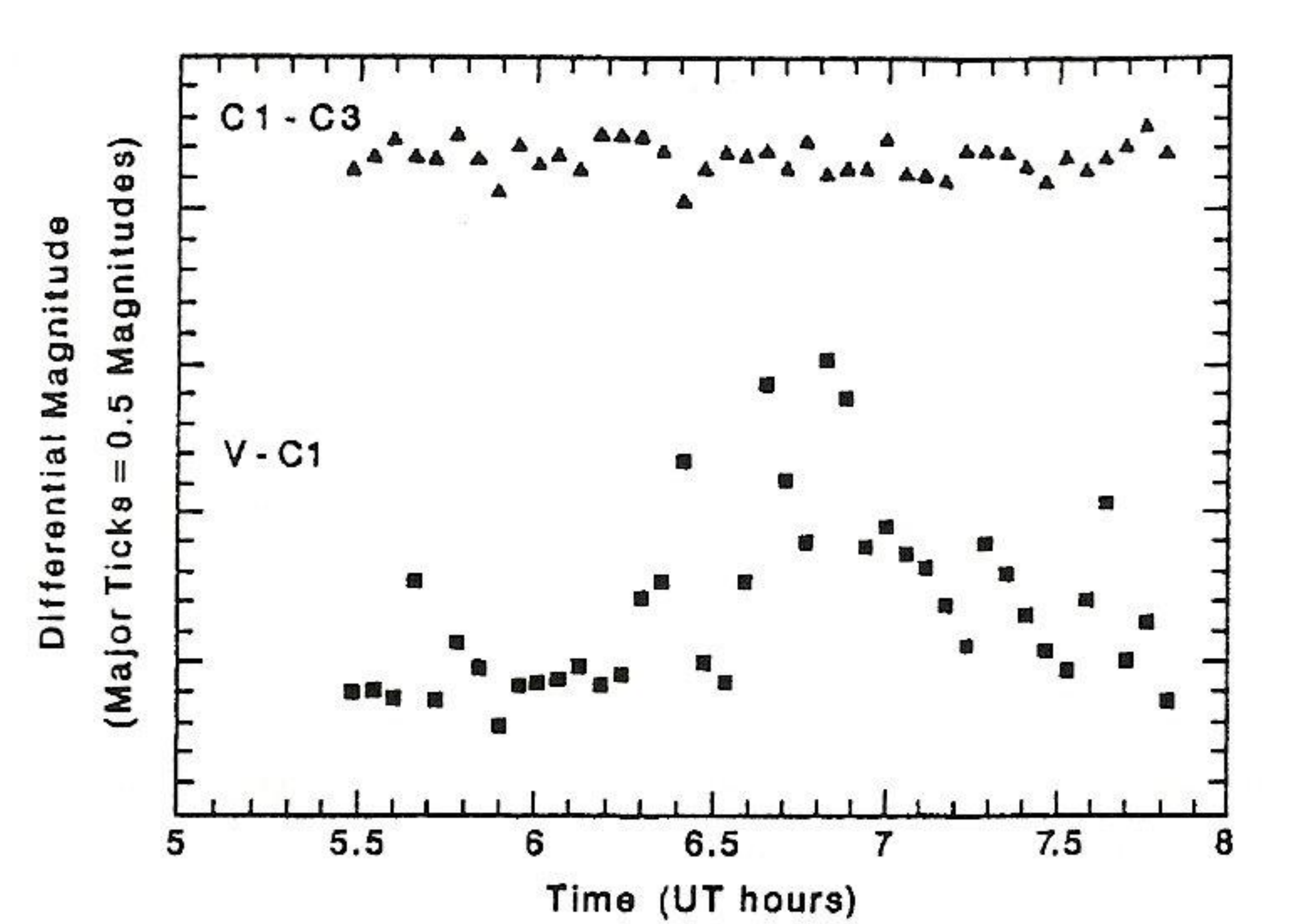
$$\sigma^2_{C-K} = \sigma^2_{C-K}(VAR) + \sigma^2_{C-K}(INST) = \sigma^2_{C-K}(INST).$$

- IF V~C~K, sigma(V-C)~sigma(C-K), otherwise proper scaling of uncertainties is required

Diff. Phot - example
Is V variable?



Diff. Phot - example
V is variable



Real Variability or not? Need to run the numbers

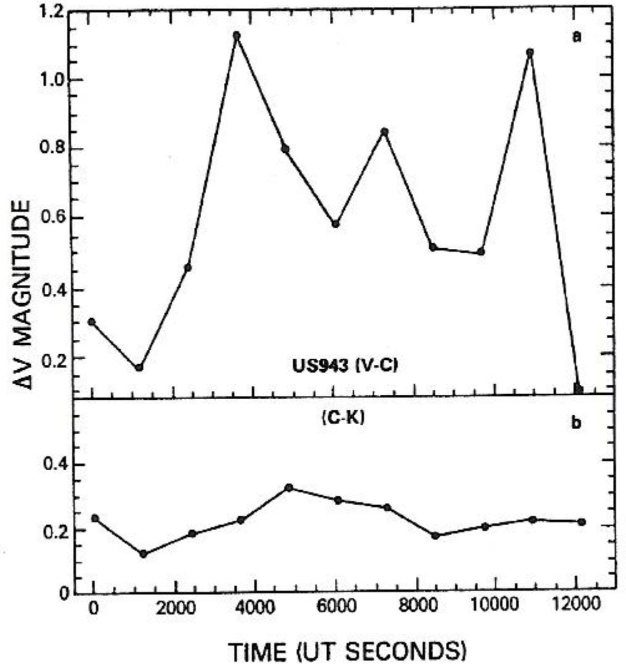


FIG. 3. Differential photometry for US 943. Part (a) shows the V − C differential light curve, while part (b) shows the C − K differential light curve. Each point represents the time of mid-exposure with the first point in each plot being that time given in Table II(b) for the start of the time series. An estimate of the photometric accuracy in the differential V data may be obtained by using s_Γ, which can be calculated from the values given in Table III.

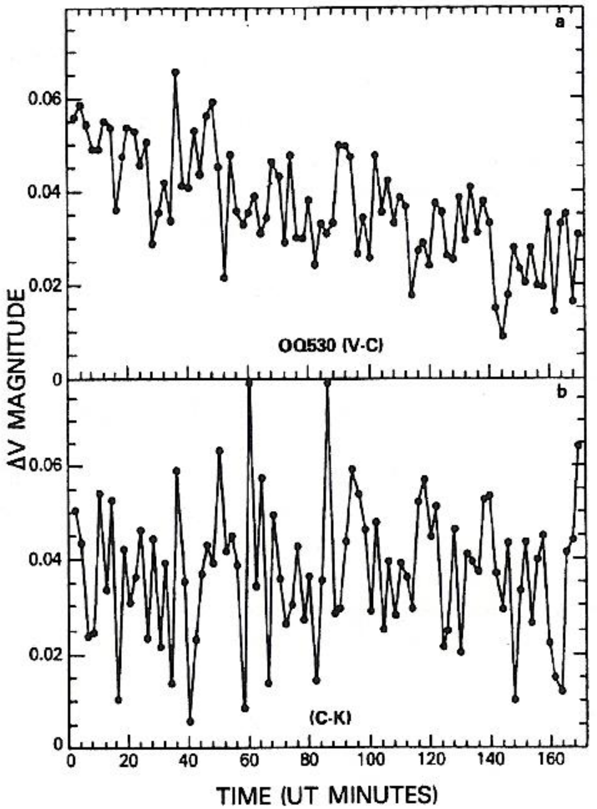


FIG. 4. Differential photometry for OQ 530. See Fig. 3 caption for a complete description.

Without proper scaling of C & K wrt V, can not tell

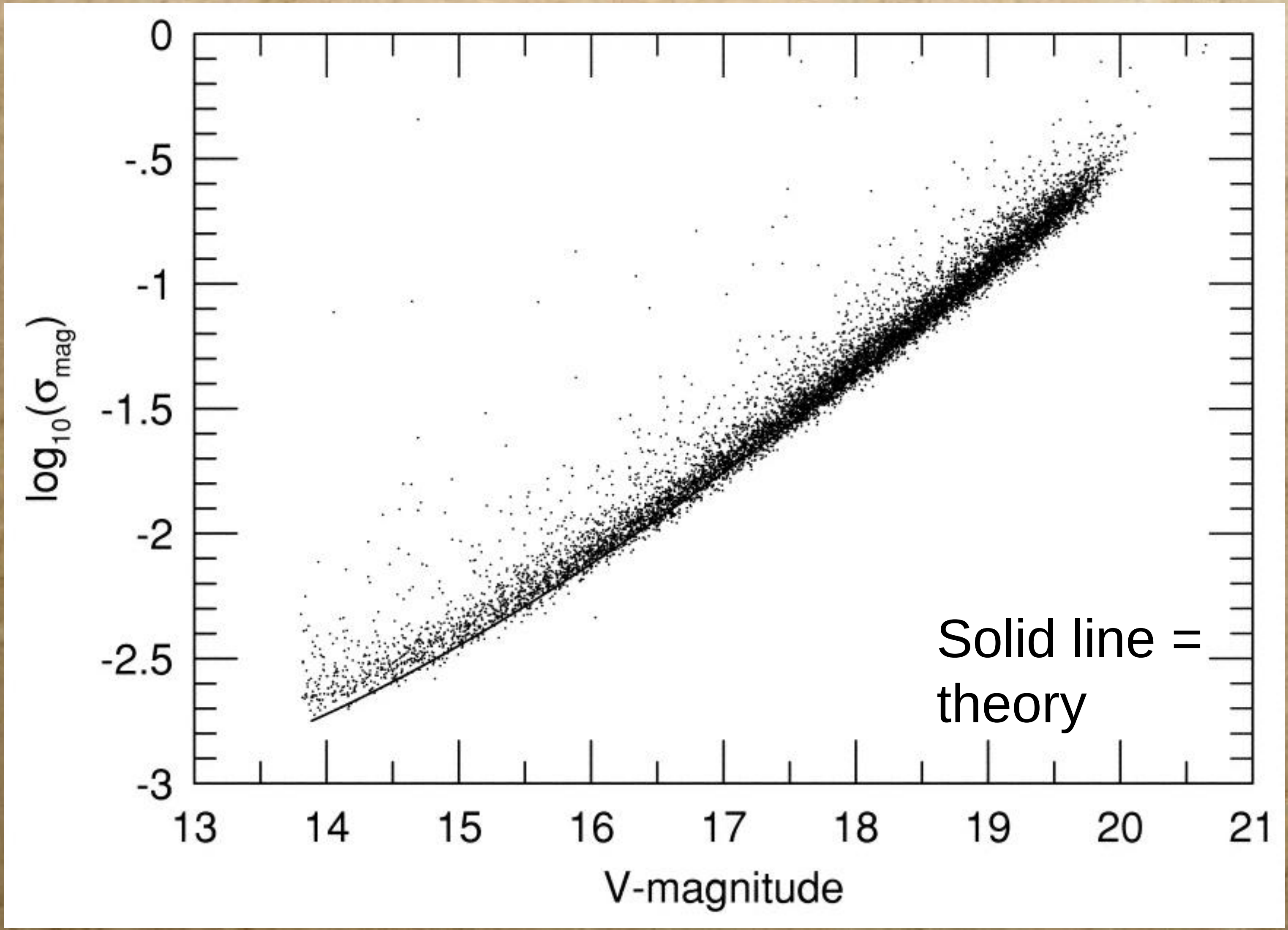
Ensemble Diff Phot

- Averaging is a powerful tool to beat down systematic noise
- Use many comparison stars (an ensemble) to compare each star to, This allows a better estimate of brightness changes
- Ensembles should be
  - 10-40 (or more) stars weighted by their uncertainties on a point by point basis.
  - Ideal ensembles are N stars of equal brightness, and the brightest in the sample
  - Ideally, ensembles are local, within a few arcminutes

Ensemble Diff Phot

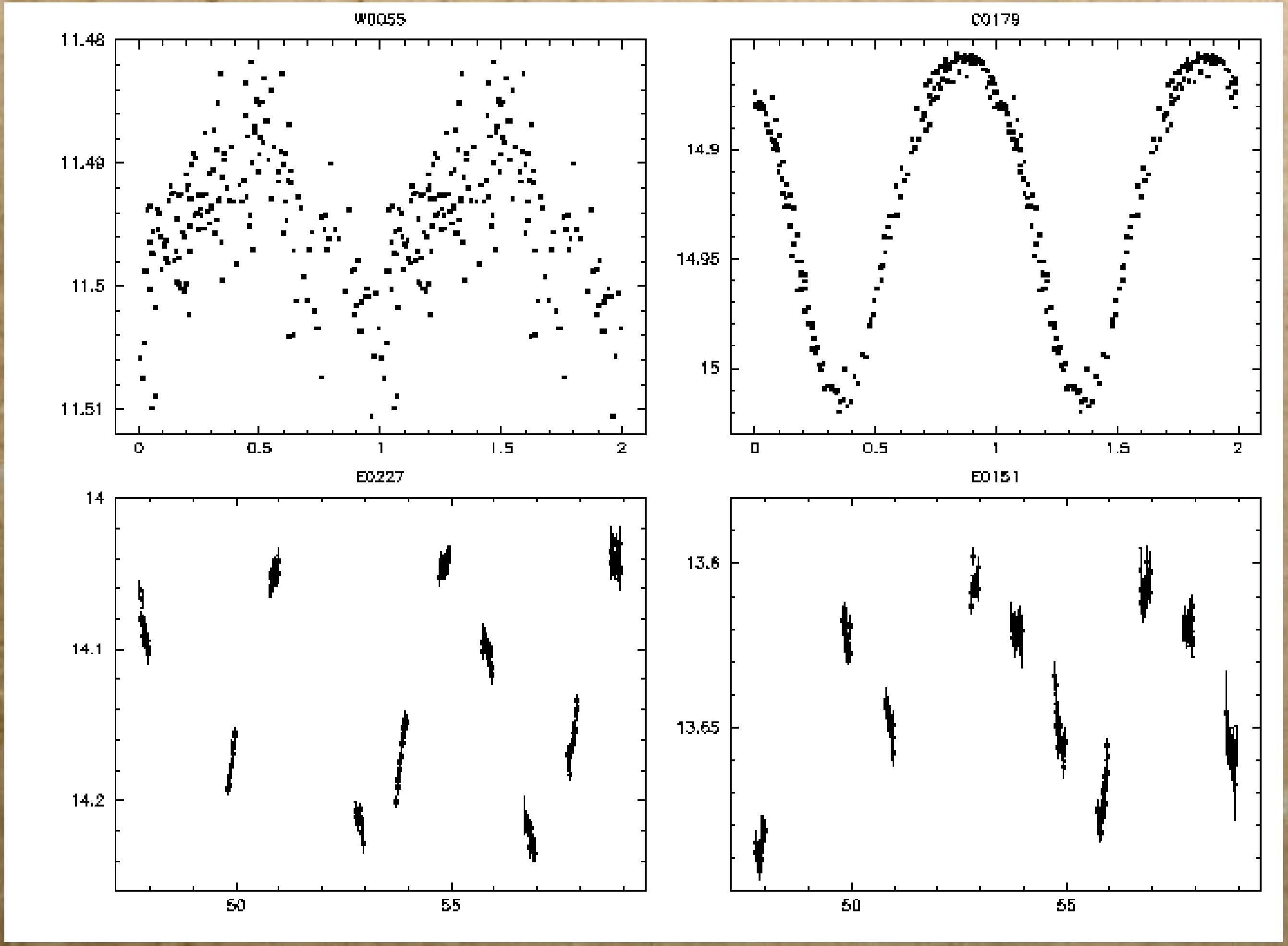
- Use iterative process to remove variables from ensemble
- Form magnitude differences:
  - Each star magnitude - Ensemble average magnitude for each frame
- Determine properly scaled error for each observed point
- Systematic and real changes are removed - only true variability remains
- Details in Everett & Howell (2001)

CCD Error curve

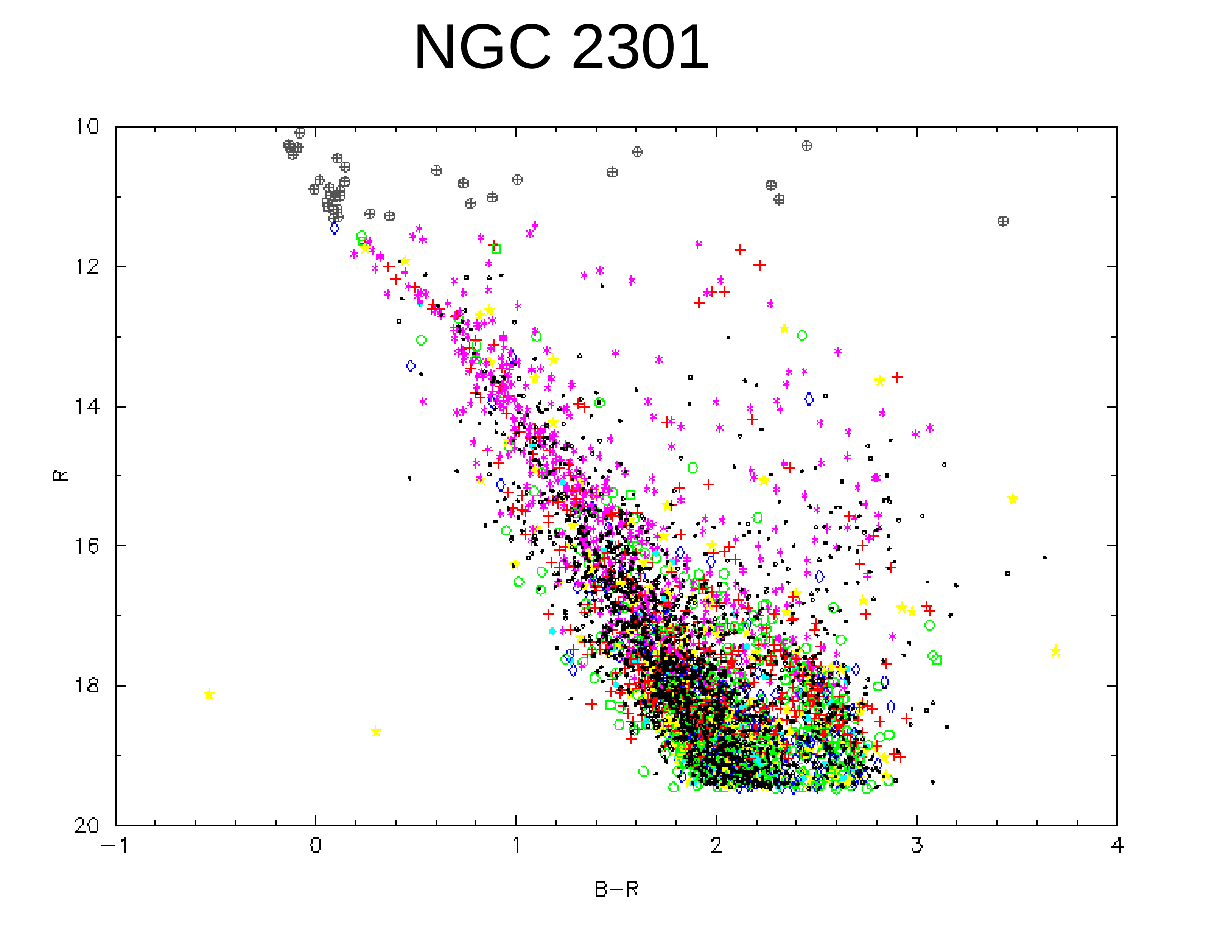


Sigma of entire light curve vs. V magnitude

Light curves



Typical Application



Variability in 10% increments by color

Essential References

- Everett and howell, 2001, PASP, 113, 1428
- Howell, Mitchell, and Warnock, 1988, AJ, 95, 247
- Gilliland et al., 1993, AJ,106, 2441
- Gilliland and brown, 1988, PASP, 100, 754
- Newberry, 1991, PASP, 103, 122
- Honetcutt, 1992, PASP, 104, 435
- Merline & Howell, 1995, Exp. Ast. 6, 163 (and refs therein)
- Diego, 1985, PASP, 97, 1209
- King, 1971, PASP, 83, 199
- Stetson, 1990, PASP, 102, 932
- Stetson, 1987, PASP, 99, 191
- Howell, 2006, "Handbook of CCD Astronomy", CUP
- Howell, 1989, PASP, 101, 616
- Romanishin, 2001, http://observatory.ou.edu
- Also see references listed within each of these major works